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TECHNICAL REPORT ARCCB-TR-94039

MONITOR FOR *STATUS EPILEPTICUS* SEIZURES

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OCTOBER 1994

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1994

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
MONITOR FOR *STATUS EPILEPTICUS* SEIZURES

5. FUNDING NUMBERS
AMCMS No. 6111.02.H611.1
PRON No. 1A13Z1CANMBJ

6. AUTHOR(S)
Mark Johnson and Thomas Simkins

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Benet Laboratories, AMSTA-AR-CCB-O
Watervliet, NY 12189-4050

8. PERFORMING ORGANIZATION REPORT NUMBER
ARCCB-TR-94039

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Close Combat Armaments Center
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Presented at Technology 2003, Fourth National Technology Transfer Conference and Exposition, Anaheim, CA, 7-9 December 1993. Published in Proceedings of Technology 2003.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes the sensor technology and associated electronics of a monitor designed to detect the onset of a seizure disorder called *status epilepticus*. It is a condition that affects approximately 3 to 5 percent of those individuals suffering from epilepsy. This form of epilepsy does not follow the typical cycle of start-peak-end. The convulsions continue until medically interrupted and are life-threatening. The mortality rate is high without prompt medical treatment at a suitable facility. The report describes the details of a monitor design that provides an inexpensive solution to the needs of those responsible for the care of individuals afflicted with this disorder. The monitor has been designed as a cooperative research and development effort involving the United States Army Armament Research, Development, and Engineering Center's Benet Laboratories (Benet) and the Cerebral Palsy Center for the Disabled (Center), in association with the Department of Neurology at Albany Medical College (AMC). Benet has delivered a working prototype of the device for field testing, in collaboration with AMC. The Center has identified several children in need of special monitoring and has agreed to pursue commercialization of the device.

DTIC QUALITY INSPECTED 4

14. SUBJECT TERMS
Neuronetworks, Epilepsy, *Status Epilepticus*, Monitors

15. NUMBER OF PAGES
9

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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EPILEPSY

Epilepsy is a disorder of the brain characterized by recurring seizures, in which there are uncontrolled electrical discharges of brain cells (ref 1). Epilepsy may arise from a very small area of damaged brain tissue, or from the entire brain. There may be no apparent brain damage, or damage limited to an area so small it cannot be detected. Therefore, in nearly one-half the cases, the cause of epilepsy is not known.

Several types of seizures are associated with epilepsy, the most common of which are generalized tonic-clonic (grand mal), absence (petit mal), complex partial (psychomotor), and elementary partial (focal motor). Each seizure type can be characterized by various symptoms. However, the seizures are generally not life-threatening, lasting at most up to three minutes. The exception is *status epilepticus*, also called continuous-seizure state. This is the occurrence of repetitive or continuous seizures and affects approximately 3 to 5 percent of those individuals suffering from epilepsy. It can exist with all types of seizures and may result in irreversible brain damage or death without prompt medical treatment.

THE PROBLEM

We were requested to develop a device that could detect the onset of *status epilepticus* in a child during sleeping hours. The seizures begin as complex partial and progress to generalized tonic-clonic. The early stages of the seizures are characterized by a loss of consciousness during which there are minor, barely perceptible tremors. The monitor was to supplement the ineffectual periodic observation of the child by the parents.

A SOLUTION

A motion sensor has been designed with nearly omnidirectional response that can detect the "hard shiver" activity characteristic of complex partial seizures. The sensor is small and inexpensive to produce since it detects without measuring. It is less responsive to casual and temporary body motion (rolling over, etc.) than to the activity of the tremors. Quasi-continuous activity for a finite period of time is used as an indication of seizure activity. Currently, any uninterrupted sensor activity detected in a contiguous sequence of time windows satisfies the alarm criteria. This approach ensures consistent results at all orientations of the sensor and reduces the number of false alarms due to casual motion. Although the monitor is designed to ignore occasional movements not indicative of a seizure, false alarms will occur. Therefore, sensitivity adjustments have been included that alter the number and length of the windows. If the alarm criteria are satisfied, a radio frequency signal will be transmitted every 30 seconds to a compatible receiver that activates/deactivates the desired alarm mechanism.

The sensor, electronics, and commercially available FCC-compliant (HBW74A) transmitter are packaged in a small, lightweight plastic housing that is easily attached to a child (Figure 1). An on/off switch is recessed in the side. A 120-V, 60-Hz, alarm mechanism (light, radio, etc.) is plugged into a compatible receiver "trained" to the transmitter signal. Although a number of devices may be used simultaneously, power consumption is limited to 600 watts. The receiver is then plugged into a wall outlet within 20 feet of the monitor. The transmitter/receiver should be manually tested to ensure the signal is properly received. The monitor is then attached to the child and powered on.

TECHNICAL DETAILS

The Sensor

The sensing element is an intermittent switch consisting of a small, electrically conductive sphere that is able to move within the confines of a small hollow cylinder with closed ends (Figure 2). The sphere and cylinder are constructed from brass and are gold-plated. The wall of the cylinder is conductive as are the end plates, each of which is separated from the cylinder wall by an insulator. The end plates are electrically connected and form one pole of the switch. The cylinder wall is the other pole. When the sphere is in contact with either of the end plates and the cylinder wall, the switch is mechanically closed. However, depending on the nature of the contact surface, the resistance may be quite high and the switch may or may not be electrically closed. The important feature is that even small motions of the switch cause the ball to roll. The mechanically-closed position (sphere in contact with the cylindrical surface B and one of the end caps A) is the only stable position of the sphere, so most rolling occurs in this position. As the sphere rolls, electrical contact with the wall is intermittent due to the variations in contact resistance. The surfaces have been tapered to improve the probability of a weighted contact. Figure 3 shows typical sensor response characteristic of the complex partial seizures to be detected. No attempt has been made to optimize the taper or utilize curved surfaces since the design of Figure 2 has proved to be satisfactory.

The Electronics

A schematic of the monitor electronics is given in Figure 4. The electronics is based on an 8-bit RISC CMOS EPROM microcontroller (ref 2). The microcontroller is designed to operate between 3 and 6 Vdc from dc to 20 MHz. High speed is not required, so the microcontroller operates at a low voltage (4 Vdc) and low clock speed (75 kHz) to conserve power. Power is derived from the 12-Vdc power source of the transmitter. A Maxim MAX874 low-dropout, precision voltage reference is utilized to supply 4 Vdc to the circuitry. This voltage reference was selected because of its low quiescent current (10 µA) and dropout (200 mV) voltage. The MAX874 sources up to 400 µA at supply voltages ranging from 4.3 Vdc to 20 Vdc. Nominal current draw of the circuit (including 12-Vdc passive transmitter operation) is 25 µA when the processor is in a quiescent mode and 85 µA during oscillation. When activated, the transmitter draws 5 mA. The useful battery life of an Eveready A23 12-Vdc alkaline battery is approximately 6 weeks when used every night for 9 hours.

With the exception of the 20-pF crystal tank capacitors, all capacitors (1000-pF) are for decoupling. The 262-kΩ feedback resistor in the oscillator circuit is required to prevent over-driving the crystal. The 100-kΩ resistor eliminates spurious oscillations and reduces standby current drain. Battery voltage is dropped by a voltage divider network and periodically monitored by an on-chip A/D converter at pin 17. Jumpers at pins 10 through 12 adjust the sensitivity by changing the number and size of the time windows used to distinguish seizure activity from casual motion. A jumper at pin 9 enables/disables diagnostic output at pin 2. Diagnostic information is transmitted through a serial link at 150 baud (6.7 msec pulses) with 1 start bit, 8 data bits, and 2 stop bits. A 1488 or similar protocol converter is required to ensure RS232 compatibility. Diagnostic output includes information on battery voltage, system configuration, and the current status of the system. Close examination of Figure 3 reveals that the sensor response is not truly digital, therefore, sensor activity is monitored using a Schmitt trigger input buffer located at pin 3. A 9155 VMOS power FET is used to simultaneously switch the transmitter and LED.

Four hundred fifty lines of microcontroller code define the system operation. Upon power-up, interrupts are disabled and the input/output port definitions established. The A/D converter characteristics are defined, but the converter is disabled to conserve power. The jumpers are monitored and the system initialized. At this point the processor could go into a "power-saving sleep mode," where the oscillator is disabled and current draw is limited to a few µA. An interrupt generated by a signal change on the sensor input would then be used to "wake-up" the processor. However, current draw exceeds 230 µA in the 500 msec required by the processor to restart the oscillator. In fact, contrary to the claims of the manufacturer (ref 2), reliable start-up at 32 kHz was unattainable, particularly with the SOIC (surface mount) package used in the design. Continuous interrupts from the sensor and on-chip watchdog timer would result in excessive current drain and a significantly shorter battery life. Therefore, "power-saving sleep mode" was avoided to conserve power and enhance reliability.

The processor continuously repeats the initialization process until it receives an interrupt indicating sensor activity. At this point, it attempts to distinguish a seizure from casual motion by looking for uninterrupted sensor activity in contiguous windows of time. Absence of activity in any window resets the processor. If the activity or battery voltage does not warrant an alarm, the processor returns to the power-saving mode. If a seizure is detected or the battery voltage is too low (9 Vdc), the processor toggles the receiver with a 500 msec pulse through the VMOS power transistor. For the transmitter/receiver control modules selected, pulse widths under 400 msec were unreliable and those in excess of 700 msec could cycle the receiver multiple times (i.e., no noticeable effect). The signal is retransmitted every 30 seconds until reset, which turns the alarm on and off periodically. This ensures the device attached to the receiver will be activated in the event an alarm condition occurs before the receiver is set, and also reduces the risk of the signal being completely masked. The LED in series with the transmitter is used as a local alarm by transmitting 25 msec bursts (3 percent duty cycle) between the 500 msec pulses. This is enough to flash the LED, but not activate the receiver.

RESULTS AND FUTURE WORK

The monitor has only recently been turned over to the Cerebral Palsy Center for the Disabled for preliminary testing. It is a replacement for an earlier design that provided much needed data. Many of the enhancements were made based on recommendations by the parents of the afflicted child. We believe the new design corrects all of the deficiencies of the earlier model, but anticipate the need for refinements as the testing proceeds.

Neural networks have been studied as a means of analyzing the sensor response and differentiating seizure activity from casual motion (ref 3). The network uses elements of the normalized power spectrum of the response data as a feature set. Our results indicate this approach provides a faster and more reliable means of accurately detecting seizures than the method currently employed.

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3. M.A. Johnson, G. Kendall, P.J. Cote, and L.V. Meisel, "Neural Networks in Seizure Diagnosis," *Proceedings of the 1994 Artificial Neural Networks in Engineering Conference*, St. Louis, MO, November 1994, ASME Press.

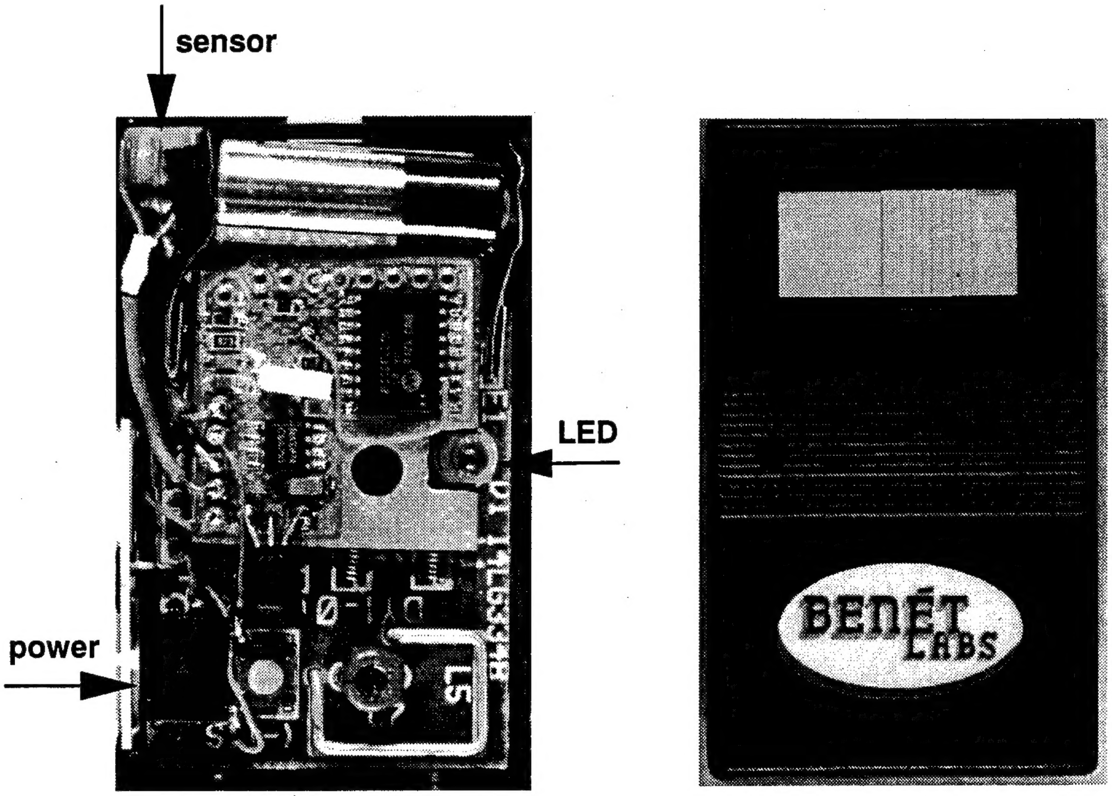

Figure 1. Monitor Hardware

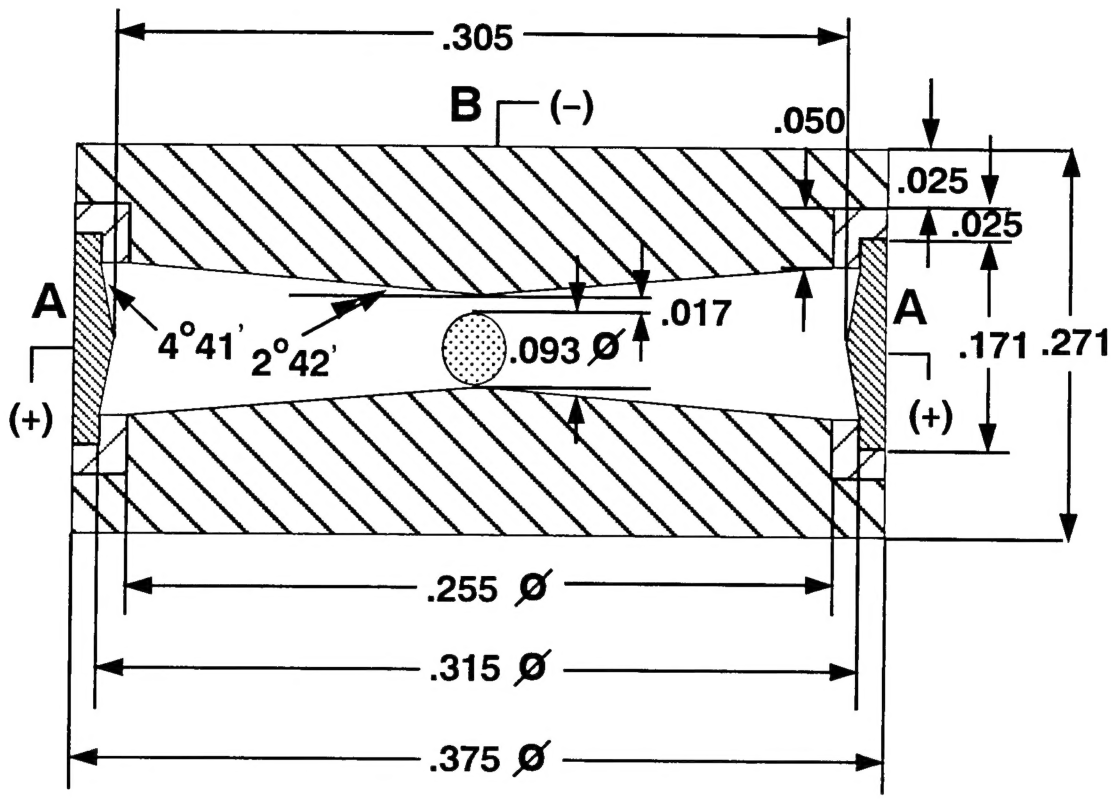

Figure 2. Sensor Cross Section

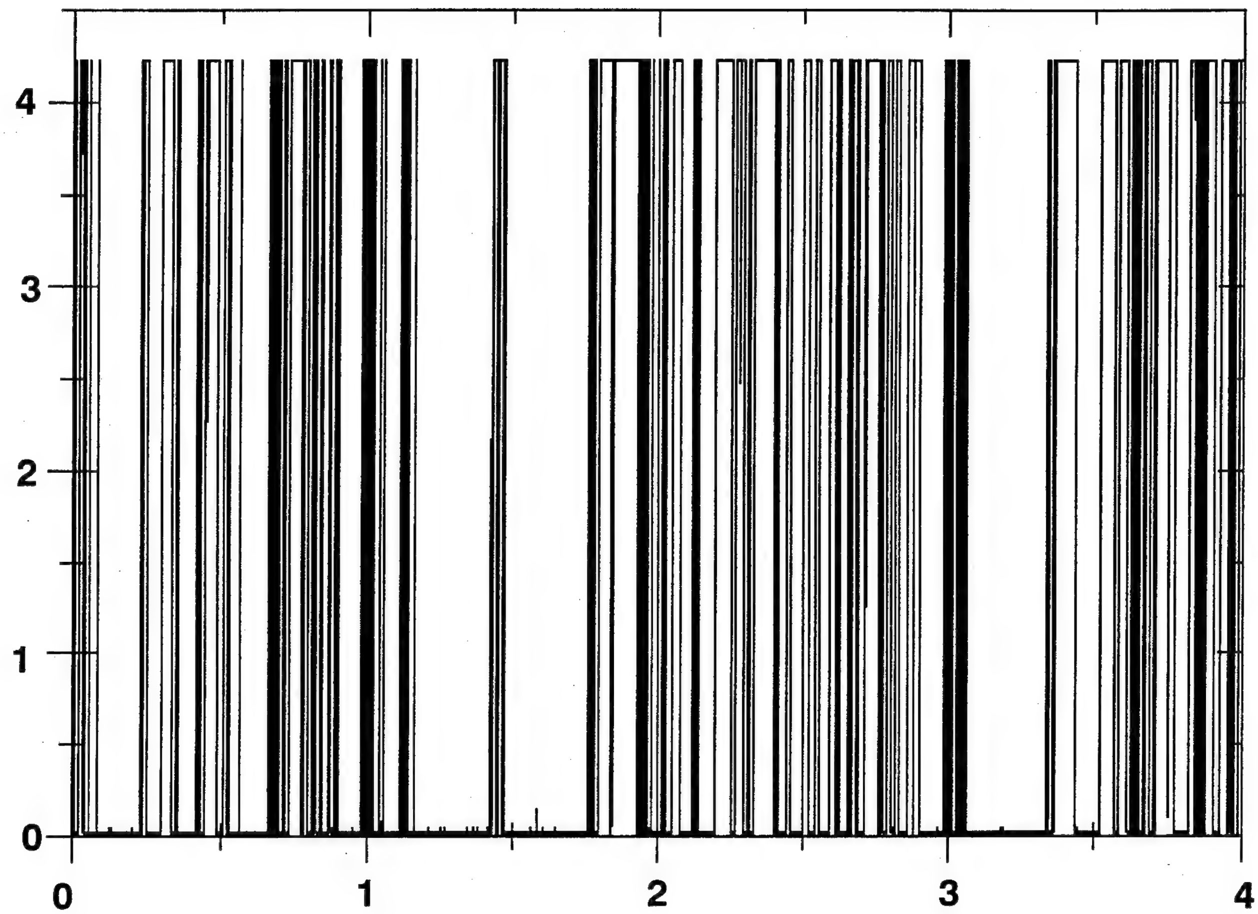

Figure 3. Sensor Response: voltage (Vdc) vs. time (seconds)

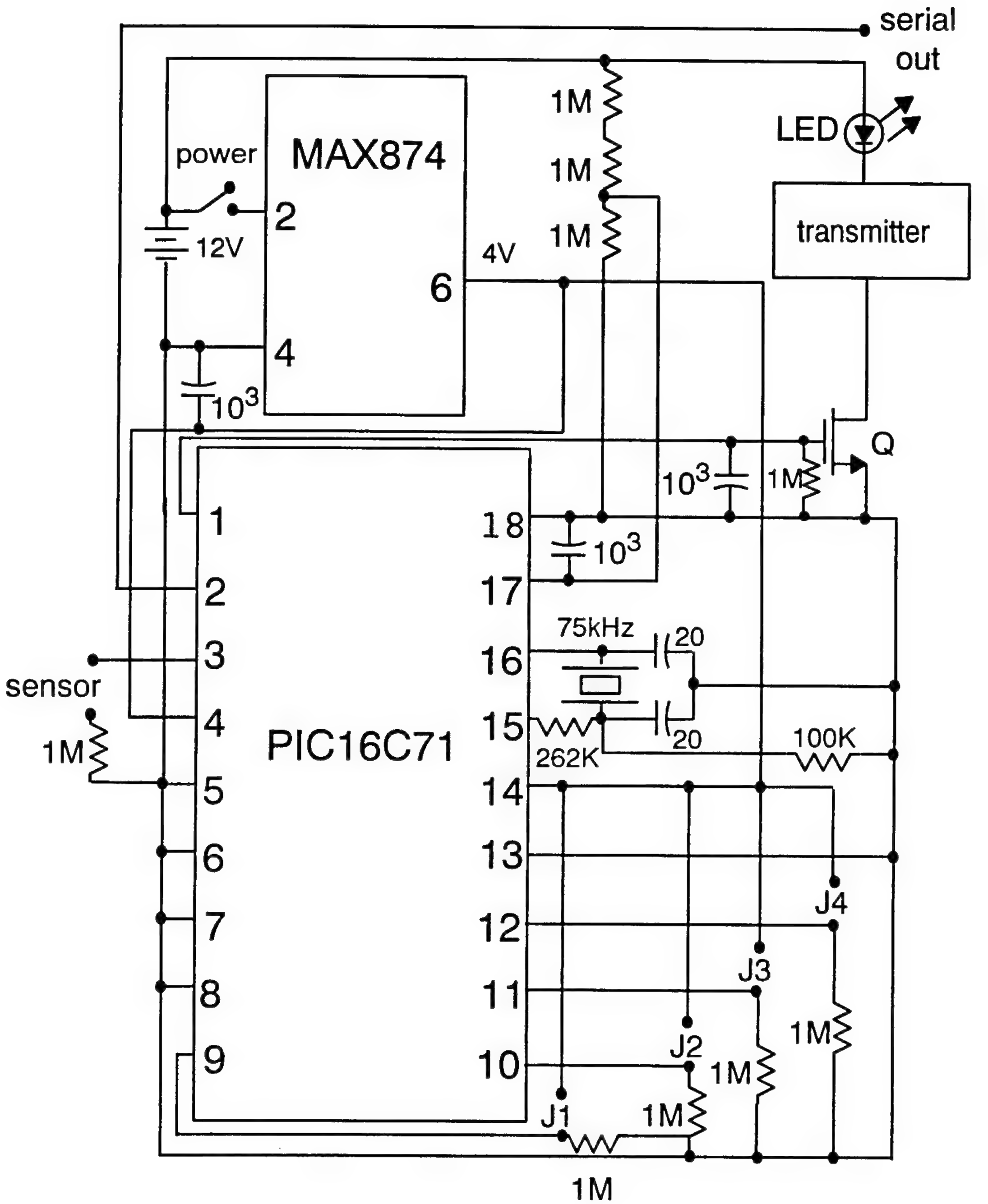

Figure 4. Monitor Electronics

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